Global Warming and the resulting climate change is one of the most serious environmental problems facing the world community. *Global Warming: the Complete Briefing* is the most comprehensive guide available to the subject. A world-renowned expert, Sir John Houghton explores the scientific basis of global warming and the likely impacts of climate change on human society, before addressing the action that could be taken by governments, by industry and by individuals to mitigate the effects. The first edition received excellent reviews, and this completely updated new edition will prove to be the best briefing the student or interested general reader could wish for.

Sir John Houghton CBE, FRS is co-chairman of the Scientific Assessment Working Group of the Intergovernmental Panel on Climate Change and chairman of the UK's Royal Commission on Environmental Pollution. He was Chief Executive of the UK Meteorological Office from 1983 to his retirement in 1991. He is author of *The Physics of Atmospheres* and *The Search for God: Can Science Help?*, and has published numerous research papers and contributed to many influential research documents. Sir John and his wife Sheila live in Wales.

Global Warming:
The Complete Briefing

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John Houghton
Co-chairman of the Scientific Assessment Working-Group of the Intergovernmental Panel on Climate Change

SECOND EDITION

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Contents

Introduction to the Second Edition

Since the publication of the first edition nearly three years ago, interest in the issue of Global Warming and concern about it has continued to grow. The Framework Convention on Climate Change (FCCC) agreed at the Earth Summit in 1992 has been ratified and machinery for its implementation is gradually being developed. At the end of 1995, the IPCC produced a further comprehensive report updating the 1990 report. Although the main conclusions have not changed, much has been added to the detail of our knowledge regarding all aspects of the issue, the science, the impacts and the possible response. This revised edition takes into account this further information from the 1995 IPCC reports.

In the first edition I included a chapter, chapter 8, with the heading 'Why should we be concerned?' which addresses the question of the responsibility of humans for the Earth and for looking after the environment. In it I presented something of the basis for my personal motivation as a Christian for being concerned with environmental problems. Although I believe that it important that science is presented in the broad context of human values, I realised that the inclusion of such a chapter was something of a departure and wondered how it would be received.

Some have expressed surprise that in the middle of a science book, there should be, unusually, a chapter of this kind which deals with ethical and religious issues. However, it has been pleasing that scientific colleagues and reviewers of the book have referred favourably to the chapter stressing the value and importance of placing environmental science in the context of the reasons for its pursuit. For instance, John Perry, in the *Bulletin of the American Meteorological Society*, writes:

> Many scientists, including avowed agnostics such as myself, will find this forthright declaration of religious belief and divine purpose a bit startling in an otherwise rigorously scientific volume. However, in a line of argument that I have no difficulty whatever in supporting, Houghton demonstrates that the domains of science and religion are simply complementary ways of looking at truth. The former deals with how the world works and the latter with why. In Houghton's framework, we and the earth are each other's reasons for existence in a divine plan that we must struggle to understand but must inescapably follow. Thus, Houghton holds that we have no choice but to care for the earth solicitously as its 'gardeners' in a 'partnership with God'. His lucid precis of the complex factual substance of global warming is an authoritative guide to the issue's scientific dimensions; his inspiring synthesis of science, faith and stewardship is an even more illuminating handbook to its moral and ethical dimensions. Together, they constitute a uniquely valuable Baedeker to one of the most important issues of our science and our time.

In revising chapter 8 for this edition, I have been somewhat more objective and less personal – which I felt was more appropriate for student readers from a wide range of disciplines, for whom the edition is particularly suited. As a didactic aid I have also included a number of problems and questions for discussion at the end of all the chapters.

Some of my colleagues sometimes comment on how formidable is the task of stewardship of the Earth feeling that it is perhaps beyond the capability of the human race to tackle it adequately. I feel optimistic about it, however, for three main reasons. Firstly, I have seen how the world's scientists, coming from very different countries, cultures and backgrounds, have worked closely and responsibly in the IPCC to provide a consensus presentation of the science of global warming. Secondly, the technologies required to provide for greater efficiency in the use of fossil fuels and for their replacement with renewable sources of energy are available and, when developed on the necessary scale, also affordable. Thirdly, my belief in God's commitment to the material world coupled with his offer of partnership in caring for it, makes stewardship of the Earth an especially exciting and challenging activity.

In the preparation of this revised volume I wish to express again my gratitude to the scientific colleagues with whom I have worked in the ongoing activity of the IPCC and from whom I have learnt much. My thanks are also due to John Twidell and Michael Banner who have commented on particular chapters, and to Catherine Flack, Matt Lloyd and other staff of the Cambridge University Press for their competence, courtesy and assistance in the preparation of the book.

John Houghton
1997

1 Global Warming and Climate Change

The phrase 'global warming' has become familiar to many people as one of the important environmental issues of our day. Many opinions have been expressed concerning it, from the doom-laden to the dismissive. This book aims to state the current scientific position on global warming clearly, so that we can make informed decisions on the facts.

Is the climate changing?

In the year 2060 my grandchildren will be approaching seventy; what will their world be like? Indeed, what will it be like during the seventy years or so of their normal life span? Many new things have happened in the last seventy years which could not have been predicted in the 1920s. The pace of change is such that even more novelty can be expected in the next seventy. It is fairly certain that the world will be even more crowded and more connected. Will the increasing scale of human activities affect the environment? In particular,will the world be warmer? How is its climate likely to change?

Before studying future climate changes, what can be said about climate changes in the past? In the more distant past there have been very large changes. The last million years have seen a succession of major ice ages interspersed with warmer periods. The last of these ice ages began to come to an end about 20,000 years ago and we are now in what is called an interglacial period. Chapter 4 will focus on these times far back in the past. But have there been changes in the very much shorter period of living memory – over the past few decades?

Variations in day-to-day weather are occurring all the time; they are very much part of our lives. The climate of a region is its average weather over a period which may be a few months, a season or a few years. Variations in climate are also very familiar to us. We describe summers as wet or dry, winters as mild, cold or stormy. In the British Isles, as in many parts of the world, no season is the same as the last or indeed the same as any previous season, nor will it be repeated in detail next time round. Most of these variations we take for granted; they add a lot of interest to our lives. Those we particularly notice are the extreme situations and the climate disasters (for instance, Fig. 1.1 shows the significant climate events and disasters during the year 1991). Most of the worst disasters in the world are, in fact, weather- or climate-related. Table 1.1 lists them in order of severity although it does not include droughts, whose effects occur more slowly, but which are probably the most damaging disasters of all.

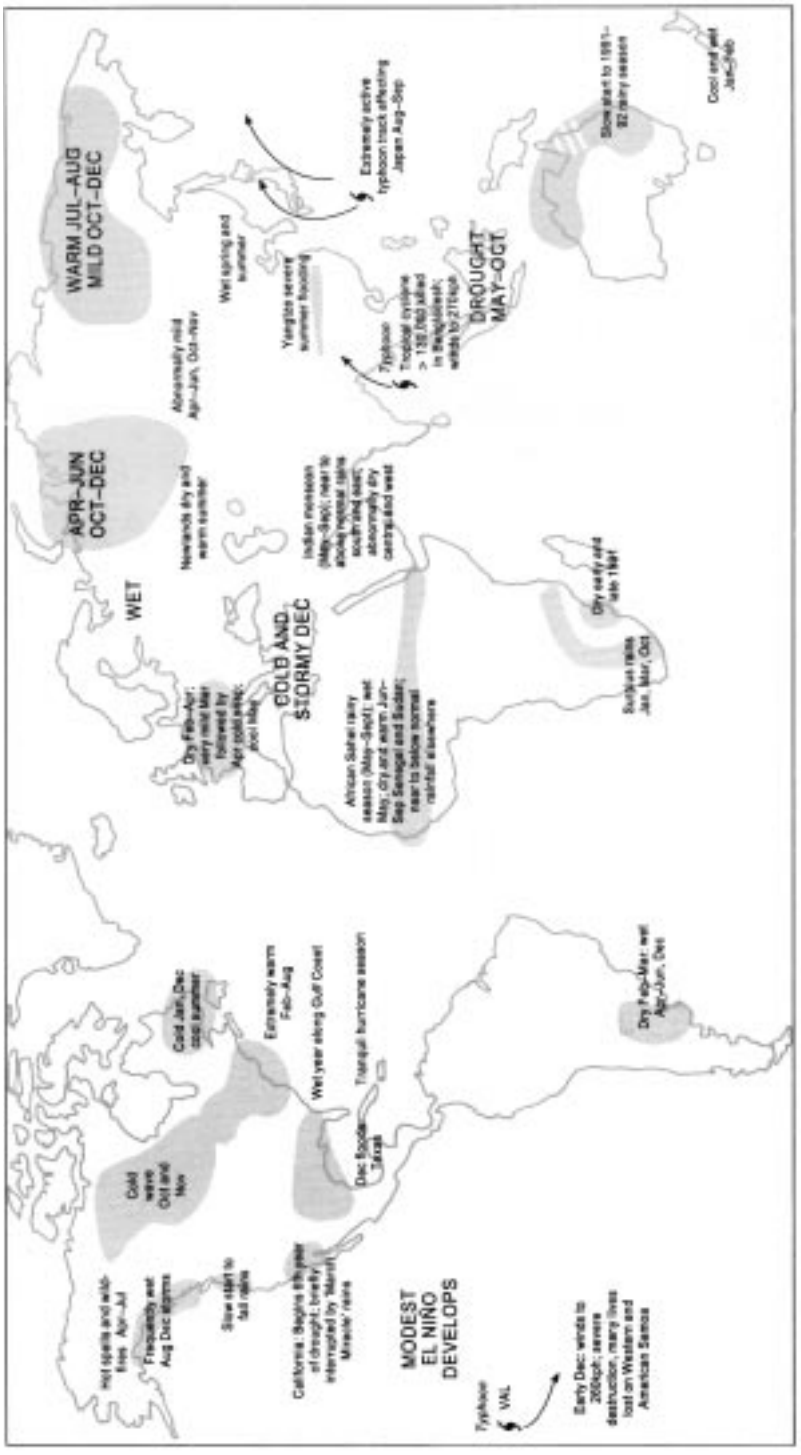

Fig. 1.1
Significant climate anomalies and events during 1991 as recorded by the Climate Analysis Centre of the United States[1].

Table 1.1
Natural disasters 1947–1980 in order of severity[2].

	Type of disaster	Deaths
1.	Tropical cyclones, hurricanes, typhoons	499,000
2.	Earthquakes	450,000
3.	Floods (other than associated with 1)	194,000
4.	Tornadoes and thunderstorms	29,000
5.	Snowstorms	10,000
6.	Volcanoes	9,000
7.	Heatwaves	7,000
8.	Avalanches	5,000
9.	Landslides	5,000
10.	Tidal waves (Tsunamis)	5,000

The 1980s: a remarkable decade

The 1980s were unusually warm. Globally speaking, the decade has been the warmest since accurate records began somewhat over a hundred years ago and unusually warm years have continued into the 1990s. In terms of global average near surface air temperature, the year 1995 was the warmest on record and eight of the nine warmest years in the record occurred in the 1980s and early 1990s.

The period has also been remarkable (just how remarkable will be considered later) for the frequency and intensity of extremes of weather and climate. For example, periods of unusually strong winds have been experienced in western Europe. During the early hours of the morning of 16 October 1987, over fifteen million trees were blown down in south-east England and the London area. The storm also hit Northern France, Belgium and Holland with ferocious intensity; it turned out to be the worst storm experienced in the area since 1703. Storm-force winds of similar intensity but covering a greater area of western Europe struck on several occasions in January and February 1990.

But those storms in Europe were mild by comparison with the much more intense and damaging storms other parts of the world have experienced during these years. About eighty hurricanes and typhoons – other names for tropical cyclones – occur around the tropical oceans each year, familiar enough to begiven names. Hurricane Gilbert, which caused devastation on the island of Jamaica and the coast of Mexico in 1988, and Hurricane Andrew, which caused a great deal of damage in Florida and other regions of the southern United States in 1992, have been notable recent examples. Low-lying areas such as Bangladesh are particularly vulnerable to the storm surges associated with tropical cyclones; the combined effect of intensely low atmospheric pressure, extremely strong winds and high tides causes a surge of water which can reach far inland. In one of the worst such disasters this century over 250,000 people were drowned in Bangladesh in 1970. The people of that country experienced another storm of similar proportions in 1991 and smaller surges are a regular occurrence there.

Table 1.2
Losses (in thousand millions of US dollars adjusted to 1992 prices) in major windstorm catastrophes 1960–92 (mostly in North America and Europe), estimated by a research group advising the insurance industry[3].

	Decade 1960–69	Decade 1970–79	Decade 1980–89	10 years 1983–92
Number of windstorm catastrophes	8	14	29	31
Economic losses	23	34	38	88
Insured losses	5	8	19	52

The increase in storm intensity during recent years has been tracked by the insurance industry, which has been hit hard by recent disasters. Until the mid-1980s, it was widely thought that windstorms with insured losses exceeding one thousand million US dollars were only possible, if at all, in the United States. But the gales that hit western Europe in October 1987 heralded a series of windstorm disasters which make losses of 10 thousand million dollars seem commonplace. Hurricane Andrew, for instance, left in its wake insured losses estimated at 16 thousand million dollars. The estimates in Table 1.2 illustrate how the numbers and extent of such disasters have increased during the past three decades. The rate of economic loss has risen by a factor of four since the 1960s while the increase in insured losses is almost tenfold. Although some of this increase is due to the growth in population over this period in particularly vulnerable areas, a significant part of it seems to have arisen from the increased storminess in the late 1980s and early 1990s.

Windstorms are by no means the only weather and climate extremes that cause disasters. Floods due to unusually intense or prolonged rainfall or droughts because of long periods of reduced rainfall (or its complete absence) can be even more devastating to human life and property. These events occur frequently in many parts of the world especially in the tropics and sub-tropics. There have been notable examples during the last decade. In 1988, the highest flood levels ever recorded occurred in Bangladesh; 80 per cent of the entire country was affected. The Yangtze river region of China experienced a devastating flood in 1991. In 1993, flood waters rose to levels higher than ever recorded in the region of the Mississippi and Missouri rivers in the United States, flooding an area equivalent in size to one of the Great Lakes. Large areas of Africa, both north and south, and of Australia have had droughts on a scale and for longer periods than any in living memory.

Because of the likely locations of floods and droughts, they often bear most heavily on the most vulnerable in the world, who can have little resilience to major disasters. Figure 1.2 shows that climate-related disasters account for more than half of all disasters for the continent of Africa and illustrates the scale of the problem.

The El Niño event

Rainfall patterns which lead to floods and droughts in tropical and semi-tropical areas are strongly influenced by the surface temperature of the oceans

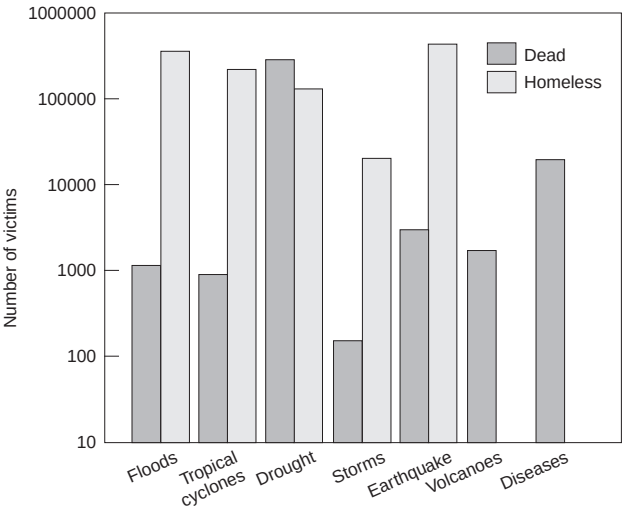

Fig. 1.2
Recorded disasters in Africa, 1980–1989, estimated by the Organization for African Unity[4].

around the world, particularly the pattern of ocean surface temperature in the Pacific off the coast of South America (see Chapter 5). About every three to five years a large area of warmer water appears and persists for a year or more. Because they usually occur around Christmas these are known as El Niño ('the boy child') events. They have been well known for centuries to the countries along the coast of South America because of their devastating effect on the fishing industry; the warm top waters of the ocean prevent the nutrients from lower, colder levels required by the fish from reaching the surface.

A particularly intense El Niño occurred in 1982–83; the anomalous highs in ocean surface temperature compared to the average reached 7 °C. Droughts and floods somewhere in almost all the continents were associated with that El Niño (Fig. 1.3). Like many events associated with weather and climate, El Niños often differ very much in their detailed character. For instance, the El Niño event which began in 1990 and reached maturity early in 1992, apart from some weakening in mid-1992, continued to be dominated by the warm phase until 1995. The exceptional floods in the central United States and in the Andes, and the droughts in Australia and Africa, are probably linked with this unusually protracted El Niño. Studies with computer models of the kind described later in Chapter 5 provide a scientific basis for the links between the El Niño and these extreme weather events; they also give some confidence that useful forecasts of such disasters may one day be possible.

The effect of volcanic eruptions on temperature extremes

Volcanoes inject enormous quantities of dust and gases into the upper atmosphere. Large amounts of sulphur dioxide are included, which through photochemical reactions using the sun's energy are transformed to sulphuric acid and sulphate particles. Typically these particles remain in the stratosphere (the

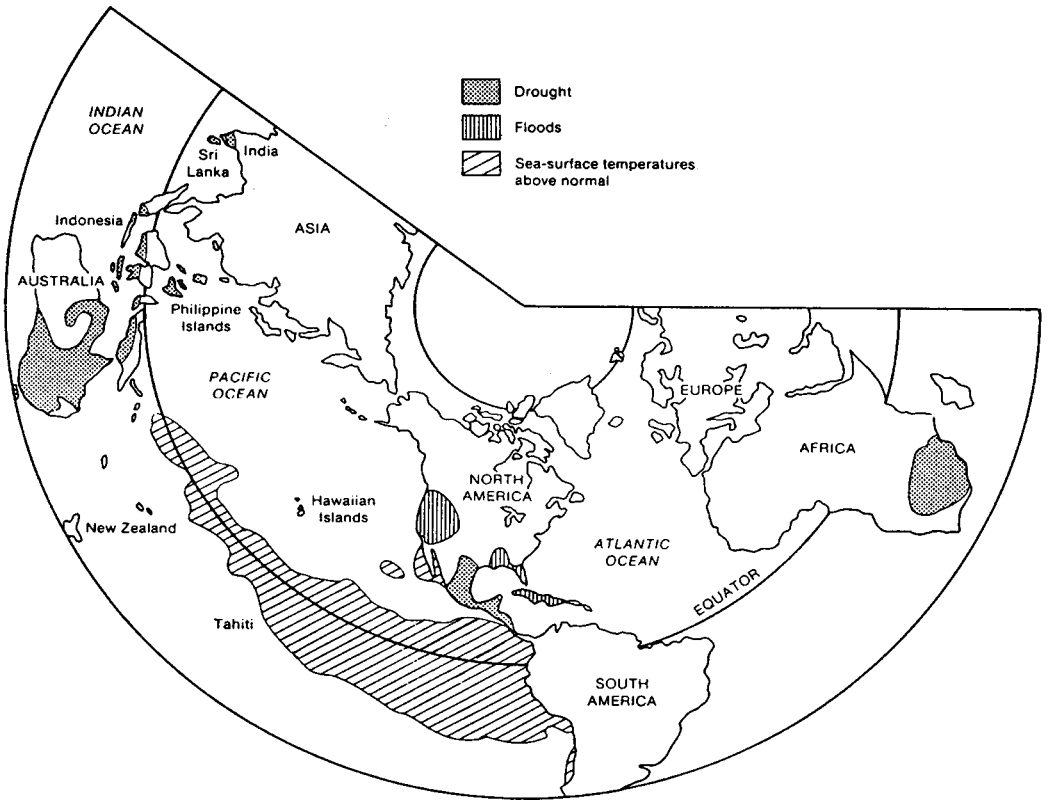

Fig. 1.3
Regions where droughts and floods occurred associated with the 1982–83 El Niño[5].

region of atmosphere above about 10 km in altitude) for several years before they fall into the lower atmosphere and are quickly washed out by rainfall. During this period they disperse around the whole globe and cut out some of the radiation from the sun, thus tending to cool the lower atmosphere.

One of the largest volcanic eruptions this century was that from Mount Pinatubo in the Philippines on 12 June 1991 which injected about 20 million tonnes of sulphur dioxide into the stratosphere together with enormous amounts of dust. This stratospheric dust caused spectacular sunsets around the world for many months following the eruption. The amount of radiation from the sun reaching the lower atmosphere fell by about 2 per cent. Global average temperatures lower by about a quarter of a degree Celsius were experienced for the following two years. There is also evidence that some of the unusual weather patterns of 1991 and 1992, for instance unusually cold winters in the Middle East and mild winters in western Europe, were linked with effects of the volcanic dust.

Vulnerable to change

Over the centuries different human communities have adapted to their particular climate; any large change to the average climate tends to bring stress of one

kind or another. It is particularly the extreme climate events and climate disasters which emphasize the importance of climate to our lives and which demonstrate to countries around the world their vulnerability to climate change – a vulnerability which is enhanced by rapidly increasing demands on resources.

But the question must be asked: how remarkable are these events? Do they point to a changing climate due to human activities? Do they provide evidence for global warming because of the increased carbon dioxide and other greenhouse gases being emitted into the atmosphere by burning fossil fuels?

Here a note of caution must be sounded. The range of normal natural climate variation is large. Climate extremes are nothing new. Climate records are continually being broken. In fact, a month without a broken record somewhere would itself be something of a record! Changes in climate which indicate a genuine long-term trend can only be identified after many years.

However, we know for sure that, because of human activities especially the burning of fossil fuels, carbon dioxide in the atmosphere has been increasing over the past two hundred years and more substantially over the past fifty years. To identify climate change related to this carbon dioxide increase, we need to look for trends in global warming over similar lengths of time. They are long compared with both the memories of a generation and the period for which accurate and detailed records exist. Although, therefore, it can be ascertained that there has been more storminess, for instance, in the region of the north Atlantic during the late 1980s and early 1990s than there was in the previous two decades, it is not clear whether those years were that exceptional compared with other periods in the previous hundred years. There is even more difficulty in tracking detailed climate trends in many other parts of the world, owing to the lack of adequate records; further, trends in the frequency of rare events are very difficult to detect.

The generally cold period worldwide during the 1960s and early 1970s caused speculation that the world was heading for an ice age. A British television programme about climate change called ‘The ice age cometh’ was prepared in the early 1970s and widely screened – but the cold trend soon came to an end. We must not be misled by our relatively short memories.

What is important is continually to make careful comparisons between practical observations of the climate and its changes and what scientific knowledge leads us to expect. During the last few years, as the occurrence of extreme events has made the public much more aware of environmental issues, scientists in their turn have become somewhat more sure about just what human activities are doing to the climate. Later chapters will look in detail at the science of global warming and at the climate changes that we can expect, as well as investigating how these changes fit in with the recent climate record. Here, however, is a brief outline of current scientific thinking on the problem.

The problem of global warming

Human industry and other activities such as deforestation are emitting increasing quantities of gases, in particular the gas carbon dioxide, into the atmosphere. Every year these emissions currently add to the carbon already present

in atmospheric carbon dioxide a further seven thousand million tonnes, much of which is likely to remain there for a period of a hundred years or more. Because carbon dioxide is a good absorber of heat radiation coming from the Earth's surface, increased carbon dioxide acts like a blanket over the surface, keeping it warmer than it would otherwise be. With the increased temperature the amount of water vapour in the atmosphere also increases, providing more of a blanket effect and causing it to be even warmer.

Being kept warmer may sound appealing to those of us who live in cool climates. However, an increase in global temperature will lead to global climate change. If the change were small and occurred slowly enough we would almost certainly be able to adapt to it. However, with the rapid expansion taking place in the world's industry the change is unlikely to be either small or slow. The estimate I present in later chapters is that, in the absence of efforts to curb the rise in the emissions of carbon dioxide, the global average temperature will rise by about a quarter of a degree Celsius every ten years – or about two and a half degrees in a century.

This may not sound very much, especially when it is compared with normal temperature variations from day to night or between one day and the next. But it is not the temperature at one place but the temperature averaged over the whole globe. The predicted rate of change of two and a half degrees a century is probably faster than the global average temperature has changed at any time over the past ten thousand years. And as there is a difference in global average temperature of only about five or six degrees between the coldest part of an ice age and the warm period in between ice ages (see Fig. 4.4), we can see that a few degrees in this global average can represent a big change in climate.

Not all the climate changes will in the end be adverse. While some parts of the world experience more frequent or more severe droughts or floods, other parts perhaps in the sub-arctic may become more habitable. Even there, though, the likely rate of change will cause problems: large damage to buildings will occur in regions of melting permafrost, and trees in sub-arctic forests like trees elsewhere will need time to adapt to new climatic regimes.

Scientists are confident about the fact of global warming and climate change due to human activities. However, substantial uncertainty remains about just how large the warming will be and what will be the patterns of change in different parts of the world. Although some indications can be given, scientists cannot yet say with a lot of detail which regions will be most affected and in what way. Intensive research is needed to improve the confidence in scientific predictions.

Uncertainty and response

Until the predictions improve to the point where they can be used as a clear guide to action, politicians and others making decisions are faced with the need to weigh scientific uncertainty against the cost of the various actions which could be taken in response to the threat of climate change. Some action can be taken easily at relatively little cost (or even at a net saving of cost), for instance the development of programmes to conserve and save energy, and many

schemes for reducing deforestation and encouraging the planting of trees. Other actions such as a large shift to energy sources which do not lead to significant carbon dioxide emissions (for example, renewable sources – biomass, hydro, wind or solar energy) in both the developed and the developing countries of the world will take some time. But here, too, a start can be made. What is important is that plans are made now in preparation for the major changes that will almost certainly be required.

In the following chapters I shall first explain the science of global warming, the evidence for it and the current state of the art regarding climate prediction. I shall then go on to say what is known about the likely impacts of climate change on human life – on water and food supplies for instance. The questions of why we should be concerned for the environment and what action should be taken in the face of scientific uncertainty is followed by consideration of the technical possibilities for large reductions in the emissions of carbon dioxide and how these might affect our energy sources and usage, including means of transport.

Finally I will address the issue of the 'global village'. So far as the environment is concerned, national boundaries are becoming less and less important; pollution in one country can now affect the whole world. And it is clear from our current scientific understanding that global warming poses a global challenge, which must be met by global solutions.

Questions

1 Look through recent copies of newspapers and magazines for articles which mention climate change, global warming or the greenhouse effect. How many of the statements made are accurate?

2 Make up a simple questionnaire about climate change, global warming and the greenhouse effect to find out how much people know about these subjects, their relevance and importance. Analyse results from responses to the questionnaire in terms of the background of the respondents. Suggest ways in which people could be better informed.

Notes

1 From *World Climate News, No. 1*, June 1992: World Meteorological Organization, Geneva.
2 After B. V. Shah, 1983, quoted. in 'Natural Disaster Reduction: how meteorological services can help', *WMO, No. 722*, 1989, World Meteorological Organization, Geneva.
3 From G. Berz and K. Conrad, 'Winds of change', *The Review*, June 1993, pp. 32–5.
4 From 'The role of the World Meteorological Organization in the International Decade for Natural Disaster Reduction' *WMO, No. 745*, 1990, World Meteorological Organization, Geneva.
5 Adapted from T. Y. Canby, 'El Niño's ill wind', *Natn. Geogr. Mag.*, 1984, pp. 144–83.